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New combustion systems for gas turbines (NGT)

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Abstract

Within the framework of an EC funded project the FLOX® [1] and COSTAIR burner technology will be investigated under gas turbine conditions. The major innovation of the project will be to show that the FLOX® and COSTAIR burner technology is applicable to gas turbine conditions, e.g. high pressure and overall lean conditions in conjunction with improved operational performance compared to lean premixed combustion. Both systems are based on the principle of diffusion combustion. The new combustion systems will be designed for micro turbines and for large scale industrial turbines. The paper gives an overview about the project and the ongoing activities. First very promising results achieved under atmospheric test conditions will be presented.

Keywords: Gas turbines; Burners; Low NO_x emission; Flameless oxidation; COSTAIR

1. Introduction

In recent years the problem of sustained oscillating combustion have become of increasing concern. The main reason is the continuing trend toward higher degrees of fuel–air premixing prior to combustion. Unfortunately, developments in premixed combustion are generally accompanied by an increase in the occurrence of oscillating combustion. Lean premixed combustors are especially susceptible to instabilities. Its basic requirement to operate of mixture strengths near the lean blow-out limit means that small perturbations in fuel/air ratio tend to produce disproportional large variations in the rate of heat release [1]. Additionally changes in gas quality due to different source of natural gas increase the oscillating problem.

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[1] Registered trade mark WS Wärmeprozesstechnik GmbH.

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In order to solve the problems with the state of the art technology and to improve the technology new combustion concepts like flameless oxidation and continuous air staging are considered as an interesting alternative to the existing combustion technologies. Within the framework of an EC funded project [2] the new combustion concepts will be investigated under gas turbine condition.

In order to achieve the targets an interdisciplinary approach with partners from industry, universities and research centres have been considered. The partners are: Gaswärme-Institut Essen, e.V.; Ruhr-Universität Bochum, Lehrstuhl für Energieanlagentechnik und Energieprozesstechnik; RWTH Aachen, Institut für Technische Mechanik; Instituto Superior Tecnico Lisboa; Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Verbrennungstechnik Stuttgart; Ansaldo Ricerche s.r.l.; WS Wärmeprozesstechnik GmbH; Delft University of Technology, Thermal Power Engineering Department; Danish Gas Technology Centre a/s; Microturbo Groupe Snecma SA and ALSTOM Power Sweden AB.

2. The new combustion systems

The combustion systems flameless oxidation and continued air staging have been developed during the last years. The flameless oxidation technology has been applied successfully to industrial furnaces and stirling engines. More details can be found in the literature [3–6]. Therefore the combustion principles will be very briefly described in the following.

2.1. Flameless oxidation

The patented combustion principle of flameless oxidation (FLOX®), developed by WS Wärmeprozesstechnik is based on high internal flue gas recirculation which leads to a dilution of the combustion zone. The high recirculation ratios are achieved by the momentum of the air and fuel jets entering the combustion chamber (Fig. 1). Controlled conversion of fuel without pulsation and with complete burn-out have been achieved with this technology.

Due to the high recirculation ratios, the maximum reaction temperature in FLOX® operation is extremely lower than in conventional combustion, thus reducing NO_x formation considerably. Recent measurements provided NO_x values < 3 ppm (at 15% O_2) at atmospheric conditions with

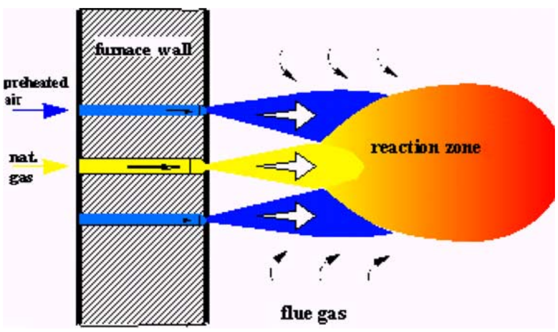

Fig. 1. FLOX® combustion principle.

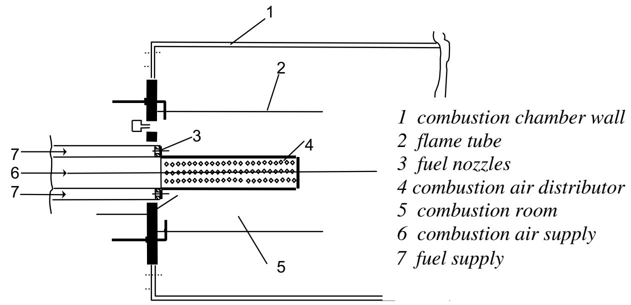

Fig. 2. COSTAIR combustion principle.

high air preheating temperatures. First computational calculations showed that even under high pressure conditions of 30 bar (adiabatic flame temperature 1672 K) NO_x emissions of below 10 ppm are predicted.

2.2. Continued staged air combustion (COSTAIR)

The COSTAIR combustion concept have been developed for application in boilers. The main principle is a continued staging of the combustion air in order to suppress formation of thermal NO. Its operation is stable and free of pulsation over a wide operating range (air ratio up to 5). NO_x emission values are <10 ppm (15% O_2) and CO emissions are <5 ppm (15% O_2) under atmospheric conditions [7,8].

Fig. 2 illustrates schematically the design of the COSTAIR burner. It consists of a coaxial tube; the combustion air flows through the inner tube (6) and the fuel through the outer annulus (7). The combustion air is distributed into the combustion chamber by means of an air distributor (4) with numerous openings. The fuel enters the combustion chamber through several jets (3) arranged around the air distributor.

3. Objectives of the project

The main objective of the project is to show, that with the new combustion systems based on the FLOX® and COSTAIR concepts the following improvements can be achieved

- elimination of pulsation in gas turbine combustion chambers,
- increase of the stability of the combustion process in a wide range of excess air ratio,
- suppression of high pollutant emissions at part load,
- increase in the efficiency of gas turbines and
- possible use of different fuels (natural gas and fuel oil).

The major innovation of the project will be to show that the FLOX® and COSTAIR burner technology is applicable to gas turbine conditions, e.g. high pressure and overall lean conditions in conjunction with improved operational performance compared to lean premixed combustion.

Both systems are based on the principle of diffusion combustion. The new combustion systems will be designed for micro turbines and for large scale industrial turbines.

4. Description of work

The starting point for the achievement of the technical objectives mentioned is the available knowledge on the FLOX® and COSTAIR burner technology. At a first step towards a new combustion system for gas turbines experimental investigations at atmospheric pressure will be carried out with a standard combustor geometry. The results of these tests will lead to burner concepts which are suitable for the gas turbine process. At the second step tests at gas turbine conditions with pressures up to 30 bar will be carried out. These experiments will reveal detailed information on the operating performance (stability, emissions, etc.) of several burner variants under specific conditions of gas turbines. This information is needed to develop the design methodology and to verify the applicability of the CFD tools and models used in the design phase. The investigations will be carried out with natural gas and fuel oil.

Flow simulation codes are today very important tools for an efficient development of new burner designs. Numerical simulation will be carried out in order to transfer the results from basic test rigs to gas turbine combustors. Unfortunately, numerical simulation of flameless oxidation is not state of the art. Therefore further development of the different combustion models is an important part of the project.

In the next step detailed experiments with the new burners which have to be designed for the application in gas turbines will be performed at the pressure levels relevant for micro turbines and for large scale industrial turbines. This requires the development of technical design criteria. It also presupposes the distribution of technical details concerning materials, process parameters and start up procedures chosen.

In order to show the applicability of the new technology under industrial conditions appropriate tests will be performed, preferably at a test rig for micro turbine combustors and at a high pressure test rig for industrial turbine combustors. These rigs will be used to demonstrate the industrial validity of the systems developed.

5. Experiments under atmospheric conditions

Up to now no information about the range of application of the new combustion systems to gas turbines are available. Therefore first tests at atmospheric conditions are designed in order to get information about the size of the reaction zone, the amount of flue gas which can be recirculated and the maximum specific heating density which can be achieved with the new combustion systems. The investigation have to provide an answer to the question if the cooling effect of the recirculated flue gas is sufficient in order to achieve low NO_x emissions.

For the first experimental work a standard test rig has been designed. The geometry of the combustor will be used by all partners in order to allow a better comparison of the different experimental results. Fig. 3 illustrates the geometry of combustion chamber and the measurement positions. The following quantities will be measured in detail: flue gas compositions (specially

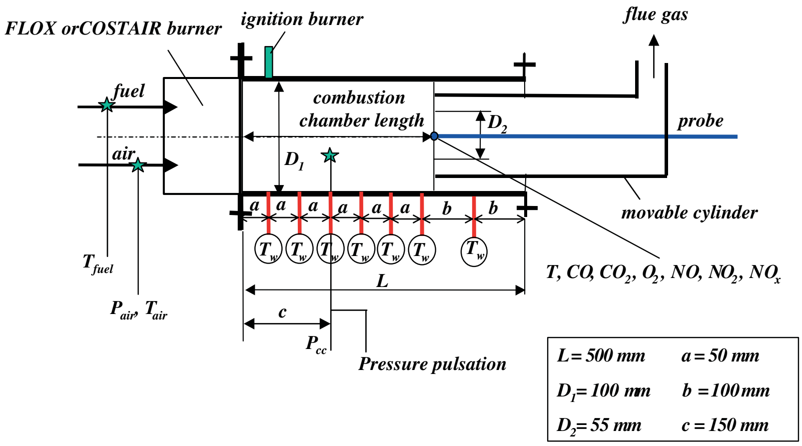

Fig. 3. Standard combustion chamber.

NO_x, CO, UHC and O_2), combustor air inlet temperature (air preheating temperature) and pressure, fuel temperature and pressure, combustor pressure, combustor wall temperatures and flue gas temperature. Additionally, flame and OH-self radiation images will be taken by a CCD camera to consider flame form and combustion intensity as well as the reaction zone length and position. To obtain information about the size of the reaction zone a movable probe is used for measuring the flue gas concentration within the combustor. A movable cylinder at the outlet of the combustor allows to vary the length of the combustion chamber.

5.1. Experimental results with natural gas

Simultaneously to CFD simulation activities experimental investigations on FLOX® and COSTAIR burners were carried out under atmospheric pressure at the combustion chamber illustrated in Fig. 3 with natural gas. A high number of experiments with different configurations for each burner principle was realised and evaluated [9]. The investigations have been carried out by Gaswärme-Institut Essen.

5.1.1. Flameless oxidation

In order to investigate if the flameless oxidation is applicable to gas turbines different arrangements of the fuel gas and air nozzles have been considered (Fig. 4).

Experimental results and numerical simulation work have shown that the lowest NO_x and CO values as well as the shortest reaction zones have been achieved for the arrangement of single nozzles FLOX® burners (multi single nozzles FLOX® burner).

The measured NO_x and CO values showed in Fig. 5 have been achieved with a combustion chamber length of 300 mm. The NO_x emissions values are between 1 and 3 ppm and CO emission values < 10 ppm for both air ratios 2 and 2.5. The specific heating density was about 10.5 MW/m^3. The pressure loss was for all measurements < 5% of the air inlet pressure.

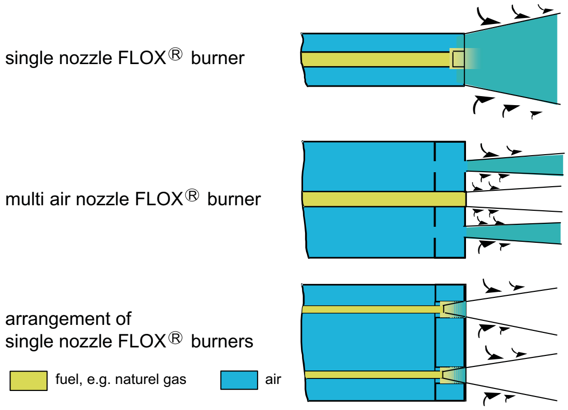

Fig. 4. Different types of flameless oxidation burners.

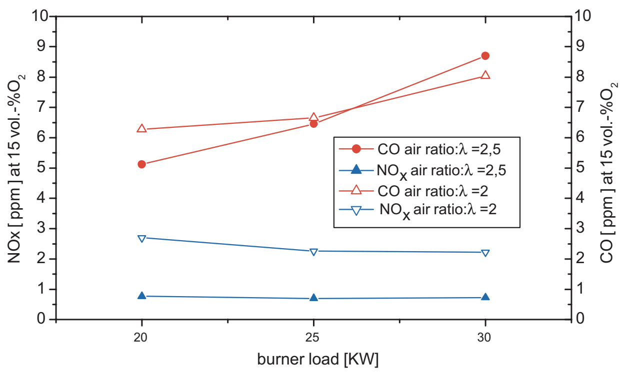

Fig. 5. Measured NO_x and CO emission values for the multi single nozzles FLOX® burner at the outlet of the combustor.

5.1.2. Continued air staging

In order to investigate if the COSTAIR burner principle is applicable to gas turbines different arrangements of the technology have been considered. Excellent results have been achieved with the COSTAIR burner shown in Fig. 6. In this case a part of the combustion air have been mixed with the fuel gas in order to achieve better combustion results.

Fig. 7 contains typically NO_x and CO emission results achieved with the COSTAIR burner. The NO_x emission values are in the range 2–4 ppm at an air ratio of 2.5 for different burner loads. The corresponding CO emission values are less than 7 ppm. At a higher air ratio of 3 NO_x emission increases slightly up to 8 ppm and CO emission also increases due to smaller changes in primary air ratio. The COSTAIR burner also worked stable at cold and hot combustor walls, as well as at high air ratio without flame extinction.

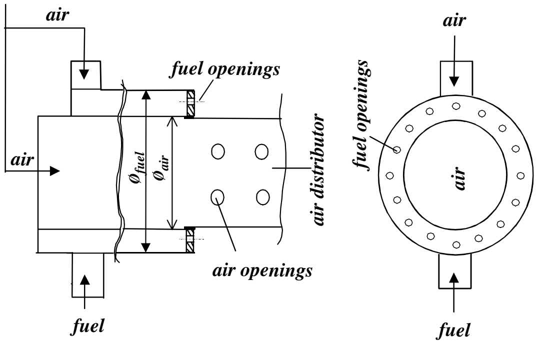

Fig. 6. Schematically design of COSTAIR burner.

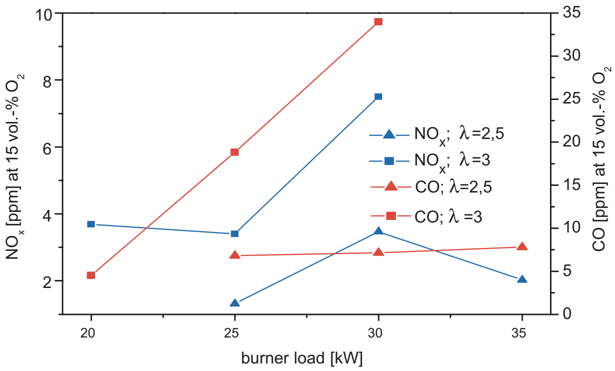

Fig. 7. Measured NO_x and CO emission values for the COSTAIR burner at the outlet of the combustor.

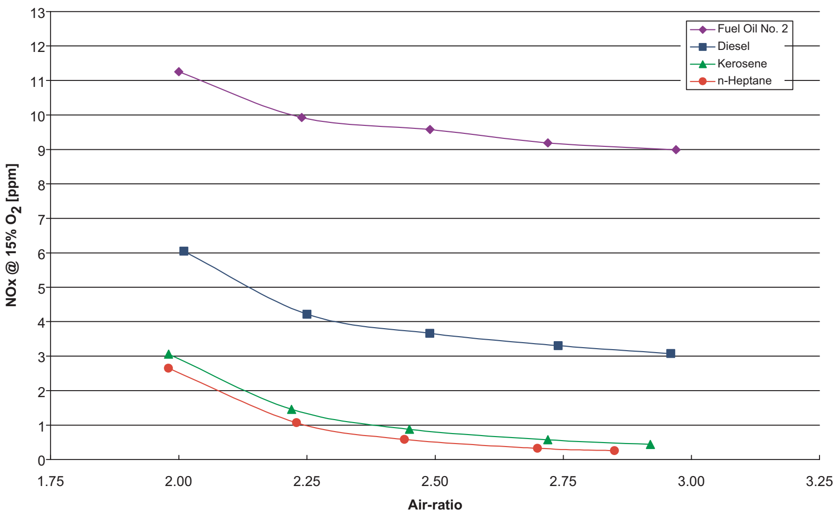

Fig. 8. NO_x emissions of a 20 kW single nozzle FLOX® burner using different liquid fuels.

5.2. Experimental results with fuel oil

In order to investigate flameless oxidation with fuel oil different arrangements of fuel and air nozzles have been considered. More information about the investigations can be found in [10]. As an example results for a single nozzle FLOX® burner and different liquid fuels are presented in Fig. 8. Compared to natural gas combustion additional sequences for atomisation and vaporisation of the fuel oil are necessary.

The curves for all fuels look very similar. NO_x emissions are decreasing with increasing air to fuel ratio. The curves for the different fuels differ in their general NO_x level and this level seems to depend only on chemically bound nitrogen. The investigations have been carried out by Institute of Energy Plant Technology at Ruhr, University of Bochum.

6. Conclusion and future work

First very promising results achieved under atmospheric test conditions. Further work at relevant pressure for micro and industrial gas turbine will be carried out in the next part of the project.

Acknowledgements

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